From Forest Nursery Notes Winter 2013

198. © How long can young Scots pine seedlings survive waterlogging? Mukassabi, T. A., Polwart, A., Coleshaw, T., and Thomas, P. A. Trees 26:1641-1649. 2012.

Trees (2012) 26:1641–1649
DOI 10.1007/s00468-012-0740-5

ORIGINAL PAPER

How long can young Scots pine seedlings survive waterlogging?

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Received: 5 March 2012 / Revised: 9 May 2012 / Accepted: 17 May 2012 / Published online: 7 June 2012

Abstract The aim of this study was to clarify the capability of Scots pine seeds (*Pinus sylvestris* L.) of different origins to germinate and survive under waterlogging conditions. Seeds were used from one Spanish and three UK sources. All experiments were carried out in the glasshouse and under the optimum conditions for Scots pine seed to germinate and establish. A technique using inner and outer pots was used to produce four depths of waterlogging below the soil surface. Seed mass and viability were examined prior to use in the experiments. Waterlogging reduced germination, but an increase in time between sowing and waterlogging of up to 3 weeks and a watertable >4 cm below the surface greatly improved germination and seedling growth. Once established, seedling survival was remarkably tolerant of waterlogging, and seedlings survived 25 months even with the watertable at the soil surface. Seeds collected from trees on a floating bog in the English Midlands were least affected by waterlogging, but the variation among seed sources was small compared to the effects of the timing, depth and duration of waterlogging. Management implications are discussed.

Keywords *Pinus sylvestris* · Waterlogging · Seedling · Germination

Communicated by G. Wieser.

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Introduction

In wetland ecosystems, waterlogging is one of the main environmental factors that affect tree seed germination and early seedling establishment (Kozlowski and Pallardy 2002). It is, however, difficult to control the level and duration of waterlogging in the field, and very few studies have investigated the effects of continuous and periodic waterlogging on germination, survival and growth (Megonigal and Day 1992).

In flooded areas, germination of woody plants is prevented or postponed by oxygen depletion and carbon dioxide accumulation (Kozlowski and Pallardy 2002), and fluctuations in flooding level determine seedling survival (Kozlowski 1997; McVean 1961), particularly in young seedlings (Brink 1954). The build-up of anaerobic organisms causes denitrification and decomposition of organic matter (Kozlowski and Pallardy 2002). In seedlings that survive, flooding causes premature leaf senescence and abscission, suppresses leaf formation and expansion of leaves and internodes, and induces shoot dieback (Kozlowski 1997). Flooding can decrease the rate of photosynthesis, lower the concentration of ATP and decreasing the absorption of macronutrients (Kozlowski 1997; Crawford 2008). Root formation and growth is often affected more than the shoots (Kozlowski and Pallardy 2002), decreasing the root/shoot ratio (Kozlowski 1997).

Several studies have shown a mixed response of *Pinus* species to waterlogging. Hunt (1951) was surprised by the limited mortality and reduction in shoot growth in flooded seedlings of *Pinus taeda*, *P. echinata* and *P. rigida*. By contrast, Sena Gomes and Kozlowski (1980) found that flooding of seedlings of *Pinus halepensis* from 10 to 70 days arrested secondary needle formation and decreased shoot dry weight. Only about half the needles remained by